Extrusion Cooking of Aquatic Feeds - The Path Forward

Historically, extrusion cooking was at best an art requiring a well-informed operator to manage the system yielding a finished product. This individual controlled everything about the process: dry ingredient flow on a volumetric basis, liquid injections by hand controls, and temperatures by cracking the valve open. All would be duly noted for the next time the product was made. The extruder barrel was assembled, and the design and placement of parts greatly affected results. All of these played a major role in control of these devices, called extrusion cookers. Initially there was simplistic control at best, with seat-of-the-pants reactions to varying conditions and challenges coming from all directions, generally resulting in total chaos, and finally shutting down to clean and start all over again. The learning curve was long, interesting and very rewarding for all of those who were up to it. Let's look at the current status of extrusion cooking and how things have changed.

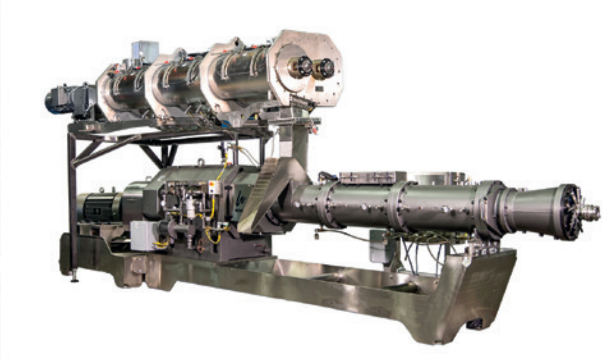

Photo of TX-300 Twin Screw Extruder

There are many methods to conduct a review, but let's do it on the basis of the generally accepted rules of extrusion, which are as follows:

1. Raw materials or formulation
2. Mechanical setup of the equipment
3. Operational parameters
4. Final product characteristics.

Raw materials and formulations have been the area of major changes in the aquatic feed sector. This area has had impacts on the mechanical and operations areas of extrusion. Fat levels, reduced availability of fish meal and fish oil, increased use of vegetable proteins, novel ingredients, as well as demanded use of indigenous raw materials all affect the process. The goal is to move from 1 to 4 in the above rules. It can be as simple as obtaining soybean meal manufactured under different conditions. Is soybean meal all the same all of the time? As shortages of fishmeal developed, the use of alternate protein sources greatly increased. This, coupled with growth in aquaculture, has strained even some vegetable protein sources. Availability might still be of no concern, but what about the ingredient quality?

Extrusion systems yield a better finished product with quality functional ingredients and low temperature dried vegetable protein sources. Protein denatures at 60-70^{0}C and as protein denatures, it becomes insoluble or non-functional. A good analogy of non-functional ingredients, which do not bind together well, would be like trying to make a ball to throw from a pile of sand. The industry adjusted when years ago fishmeal inclusion increased in salmon diets and difficulties arose from high temperature produced fishmeal. Pellets did not have the final characteristic as desired, and had no strength of form. Formulation, configuration and operational factors were all addressed in that era. In the case of vegetable proteins, the Protein Dispersibility Index (AACC Official Methods 46-10, 46-23, 46-24, 1976) is a lab test that gives an indication of the functionality of soy ingredients. The more soluble in water, the better the ingredient. The following photo shows the difference in colour which relates to heat damage when a soybean product is dried after solvent extraction. The darker the product, the lower the PDI, and this also relates to lower solubility. Projections of this to other vegetable proteins show similar traits: higher heat damage and lower functionality.

Photo: Soybean Meal Colour and Solubility. Dark Colour, low solubility, Light Colour high solubility

Another major formulation factor in aquatic feeds is the starch level, and the rules might have to change. It was generally considered adequate if 10 % starch was included for sinking feeds and 20 % starch for floating feeds. This is on a total basis from the starch in ingredients, as well as possibly added starch. Extruders bind the materials together in a matrix as opposed to forcing the ingredients as in compounding feed technology. Soluble proteins aid in this matrix development. Low PDI ingredients need something to assist in the binding of the formula together, and it might be that additional starch or higher quality starches are required if lower quality ingredients are used.

Grinding is another critical factor in the raw material area. Good grinding is a plus for extrusion as well as compounding feeds. Grinding should be followed by sifting to get the desired particle size. As smaller and smaller aquatic feeds are desired by the industry, smaller die holes and thus finer ground materials are required.

Mechanical setup of the equipment is not just a topic for the extruder but for the entire plant design. Some examples of topics for discussions are the actual raw materials and bin designs for proper flow, pre-grinding or post-grinding, double mixing to avoid grinding vitamins and select ingredients, and plant design for sanitation. The above ingredients were discussed in general. One of the advantages of extrusion when compared to compounding feeds is that the starch level normally needed is reduced, opening up the formula for a wider range of good quality protein ingredients. Ingredients with lower total protein levels can be combined to achieve the proper amino acid mix as well as the desired level of total protein.

Using various levels of a wide variety of ingredients required improved preconditioning and elevated use of water and steam to overcome varieties of vegetable and terrestrial proteins and other fibrous ingredients. Conditioners now exist for added flexibility; try preconditioning a product with 50 % fresh meat slurry (by product from terrestrial or aqua-based animals), 11.5 % steam added and achieve 3.4 minutes retention time with 35 % moisture and yield the desired free-flowing characteristics. Free-flowing material into the extruder barrel is needed for continuous operation without downtime due to flow blockage.

Photo of a High Intensity Preconditioner (HIP)

Ever-changing ingredients and the desire to understand the conditions needed or required for optimum extruder operation resulted in the development of a specialised piece of equipment, the phase transition analyser (PTA), to assist in understanding or predicting how extrusion equipment needs to be operated and configured for the desired end results. It has also been used to understand on a "what happened" basis. Individual ingredients or groups of ingredients are placed in a containment area where heat and pressure under varying moisture levels allow generation of points for curves to be graphed. In essence, the extrusion process is defined by glass transition and melt transition curves. Eventually understanding of the data allows for explanations as to why some pellets are different in terms of their structural final form.

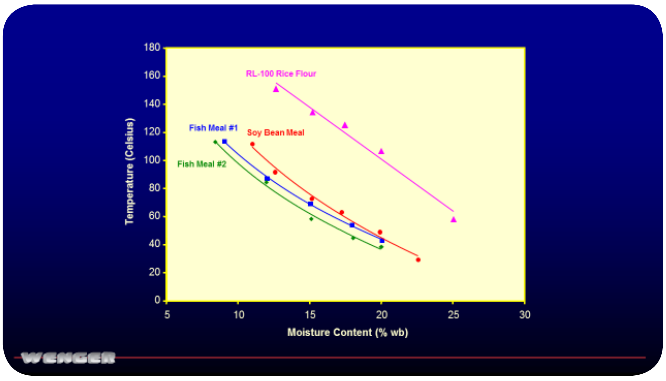

Photo of graphed results from a PTA study: With these particular ingredients it can be seen that water content greatly affected the temperatures needed for compaction or flow movement in these cases.

Photo of table-top lab equipment. Phase transition analyser.

Modifying the extruder components yields various results, depending on the actual design. As noted, different ingredients and their quality require various levels of liquid and energy inputs. The configuration of the actual extruder barrel for increased or decreased residence time or changing of the cooking effect can be accomplished by a number of methods, but this greatly improves the ability of the system to handle varieties of formulations. Historically, the machine was stopped and the parts changed to achieve the required effect. Devices are available to manipulate the cooking effect in the barrel while running, yielding less downtime and predictable control adjustments almost on an instant basis.

Many extrusion systems require the operator to visually see what is going on and take corrective action to overcome any situations in making the final product, the last of the extrusion rules, and the characteristics of the finished product. While doing so it is usual to verify the other area of importance in an extrusion system, the dryer. Today's high capacity system all require some form of drying for moisture removal. Not only is it a major area that determines operation profitability, but it is important to the downstream processes and results. Simply stated, different levels of water need to be removed based on product diameter and capacity or production rates into the dryer. Temperatures, belt speeds and air flows are adjustable and dependent on the product being made, and affect the final product quality. Evenness in drying gives the product the conditions for proper coating and qualities desired. A tight moisture variance will yield similar results in terms of oil variance after the coater.

Operational parameters or the running conditions of the process are also quite important, and a viable way to control the outcome. Variations of water and steam are essential for formulation variances as well as a key factor in floating or sinking products, let alone slow sinking. Accurate and proper inclusion in the conditioner and extruder barrel allow for the exacting but seemingly always changing levels needed based on formulation fluctuations over time.

The question is what has changed over the years in controls? In terms of operation, raw materials are metered in, water and steam and other liquids are added in the conditioner and extruder barrel, and product comes out the end. Manually this can be accomplished, but computer controls can do it faster and more accurately. The true answer is everything has changed, and nothing is exactly the same although it is similar. Starting with the dry feed system, most use a compensated loss-in-weight system ensuring the exact amount of dry material by weight is introduced into the extruder each and every moment. Liquid flows are slaved to the dry flow rate for exact inclusion via flow meters and motorised control valves. All of this is easily accomplished by a computer control system. How can you dry evenly if the material from the extruder is in a constant state of fluctuation? Let's take it up a level to not only controlling liquid inputs, but also product qualities, out of the extruder.

Computer systems can accurately control all dry and liquid ingredients; couple this with density management for +/- 20 % on a gram per litre basis and this starts to get interesting. The correct dies, getting you in the right range for control, and motorised flow restriction for increased pressure, shear and temperature mounted on the end of the extruder puts control at a new level. Add into the system an in-line sensor between the extruder and dryer for verification and control feedback. Detect and verify the density and send the information to the computer, allowing for adjustments in specific mechanical energy (SME) inputs to modify the density at the end of the extruder automatically, with no operator adjustments. SME is an important factor that can be related to product quality in terms of possible oil infusion after the dryer, exacting densities of the product and verification of the energy input for species where GDAS, gastric dilation air sacculitis, is a factor.

Photo: Basic unit to collect bulk density and moistures ON line courtesy of Source Technology.

Dryers, as mentioned, are also an important aspect of extrusion cooking. Water is required for extrusion and thus water removal is also critical to avoid shrinkage as well as making the best product. Proper dryer designs allow for moisture variance out of the dryer at 0.5 % variance across the dryer discharge bed. This is not taking moisture out of one common discharge point but from a cross-sectional location at the discharge for absolute verification of evenness in drying. In-line sensors or testing devices can verify after-dryer moisture results. Additional systems are available to control energy usage. Monitoring all of the discharge flows from a dryer gives insight on how to manage the dryer for effective energy usage.

Bringing it all together, predictability is the factor achieved in total control of the extrusion system. Control is placed in management's hands with off-site access, trending of key parameters, defined bands of operation, maintenance alarms and system fault alarms, to mention a few. Improved extrusion from more accurate ingredient input control results in perfect product from the extruder. Sounds simple, but the total attention to all aspects of extrusion is what matters; no more balling up of ingredients in the down spout requiring downtime to clean, which gives a pure benefit from better preconditioning. Improved extrusion barrel components include density control devices, so we no longer need to stop the extruder to make a change, but can simply do it while running. Add computer control and on-line sample detection and the system can control itself on such aspects as density, moisture levels and energy inputs. An improvement of 2 % efficiency in an 11-ton-per-hour plant is five additional tons per day, 24 hour operation.

Evenness in products from the extruder has allowed for the dryers to advance in areas of moisture variance and lower energy usage. Evolution of dryers was basically right behind extruders. This was not easy, not knowing until the extruders were up to speed. Extrusion of constant moisture, density, internal cell structure and product diameters were all factors in dryer advancements. Analysis of dryers has also advanced with design improvements, and commitments to sanitation in order to meet the industry needs.

The results are more even moisture out of the dryer at elevated levels for less shrinkage, constant conditions for evenness in oil and other liquid coating applications, and fewer returns and rework from a balanced system.

Extrusion has changed; it has moved from an art to a science. Technology has surrounded this field and it will be hard to back away as the results point to improved production quality and bottom line results from new designs and computer control capabilities.

Joseph P. Kearns, Vice President Aqua Feed Division for Wenger Manufacturing, has multiple patents on aquatic feeds and methods of production. He graduated from Kansas State University in engineering and has been with Wenger since. His involvement in the extrusion cooking field worldwide has resulted in an understanding of the needs for the industry on many styles of feeds. He can be reached at jkearns@wenger.com.